The Optimal Operation Design for a Three-effect Vacuum Evaporator (TEVE) and an Energy Performance Assessment

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Abstract—**Vaporized concentration is an operation process that requires a large amount of energy consumption. A three-effect vacuum evaporator (TEVE) has been widely used to reduce energy demand. However, it still requires external hot and cold functions. In this study, we showed that a TEVE saved energy under standard operating conditions in a food processing plant. A heat pump was combined with the TEVE (producing a TEVEHP system) to further save extra energy. The net present value (NPV) for the heat pump investment assessment was US$ 38,856 after five years of operation, and the break-even period was 10 months. This study also developed a multiple equation for the TEVE system that included four production parameters: input gelatin loading, input gelatin temperature, output gelatin concentration, and steam loading. This equation can simply and usefully calculate the TEVE operating and energy consumption data, and these data can be used to control the process to reach the optimum production conditions of the TEVE.**

Keywords-vacuum evaporator; vaporized concentration; heat pump; gelatin

I. INTRODUCTION

In the food industry, vaporized concentration is an important operational process that removes excess water from food. The process not only makes the food convenient to store and transport but also enhances the commercial value of the product. However, heating food to 100 °C to vaporize the water requires a large amount of energy, which increases the operational cost. Furthermore, the high temperature may adversely affect the food's flavor and decrease its commercial value.

To reduce energy consumption in food processing plants and preserve the food's flavor, a multiple-effect vacuum evaporator (MEVE) has been widely used to vaporize water under lower temperatures. For example, orange juice [1, 2], wine [3], and ketchup [4, 5] are vaporized and concentrated at a low temperature.

However, a MEVE requires extra heat energy from boiler steam. The emission steam from a MEVE also needs to be condensed, which requires cooling water to reduce the steam temperature before it discharges to ambient atmosphere. From an energy conservation and environmental protection viewpoint, the simultaneous energy demand and emission from a MEVE is an energy waste and pollutant.

Energy consumption can be reduced [6] and the food's flavor can be preserved [7] when the effect number of a MEVE is increased [8]. Unfortunately, it is very difficult to do so in an old factory without changing the existing operating conditions. The modification technology is complex and costly because there is an energy and mass balance problem under vacuum.

In this study, we used a three-effect vacuum evaporator (TEVE), which is a type of MEVE, to reduce the heating energy demand and to decrease waste heat emission in the survey food plant. The existing operating parameters were not changed and the TEVE was not modified.

The return on investment for the study used the net present value (NPV) method. Furthermore, this study developed a multiple equation for the TEVE system that included four production parameters including input gelatin loading, input gelatin temperature, output gelatin concentration, and steam loading.

II. RESEARCH MATERIALS, METHODS, AND THE CASE STUDY

A. Solution

In this study, the concentrated solution was an aqueous gelatin solution, which was extracted from animal skin or bones [9]. It was a denatured collagen that contained a high molecular functional group in the gelatin's amino acids solution [10]. The low concentrated primary extracted gelatin solution needed to be purified, concentrated, and dried to enhance the commercial value [11].

In the food industry, a variety of procedures is applied to remove water from the solution to concentrate the aqueous gelatin [12]. However, the gelatin solution is a heat-sensitive material. If the vaporized concentration is processed under high temperature, the gelatin's amino acid molecules will

irreversibly crack, lowering the quality and commercial value of the gelatin [13].

B. The Conventional TEVE System

A conventional TEVE was used to heat the gelatin solution to increase its concentration under vacuum. Fig. 1 shows the schematic of the TEVE system. A falling film (FIII-TVR, APV Anhydro AS, Denmark) TEVE was used in this study; it is a shell and tube heat exchanger. This type of TEVE has low-pressure loss and low damaging properties and is often used in a high-quality vacuum system to ensure product excellence. The gelatin solution continuously flowed into the evaporator top, and then uniformly fell by gravity onto the vertical tube sides, in parallel, to form a vaporized film around the tube wall. The steam, as the heating source, was supplied to the shell side to heat the solution and vaporize the water; it was condensed for reuse. The concentrated gelatin solution was discharged from the tube bottom [14].

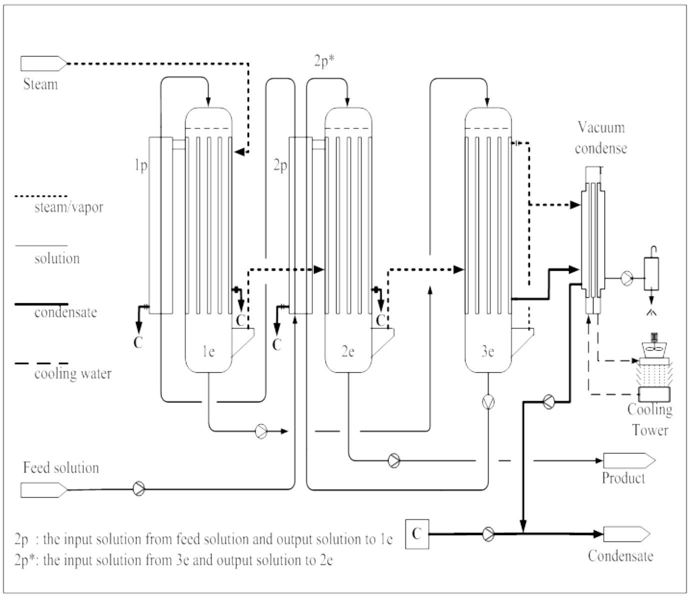

Figure 1 Three-effect falling film vacuum evaporator system (TEVE) schematic and flow diagram.

Although, the TEVE is an energy-saving device, external steam was required to increase the solution temperature in both the first effect (1e) and the pre-heater (1p). The discharged steam from the first effect was used as the heat source for both the second effect (2e) and the pre-heater (2p). The discharged steam from the second effect was used as the heat source for the third effect (3e). Finally, the discharged steam from the third effect was condensed by cooling water in the vacuum condenser. When the steam was condensed, the reduced steam volume generated negative pressure (vacuum) for the TEVE operation. All of the condensed water from the steam was recycled and reused.

C. Advanced Gelatin TEVE Process Combined with a Heat Pump (TEVEHP)

Lazzarin [15, 16] reported that a heat pump increased energy utilization efficiency in a thermal process, and further decreased energy demand in heating and cooling processes. In agreement, Langley and Billy [17] state that the heat pump is a high-efficiency energy conversion device superior to general heaters. When compared with general hot water heaters such as electric, gas, and diesel heaters, heat pumps have a higher energy efficiency. Therefore, combining a heat pump with a TEVE (a TEVEHP system) further improves energy utilization. Fig. 2 shows the TEVEHP flow diagram. The TEVEHP is a balanced heat system [18, 19] and energy savings can be reached without any change to the operating system.

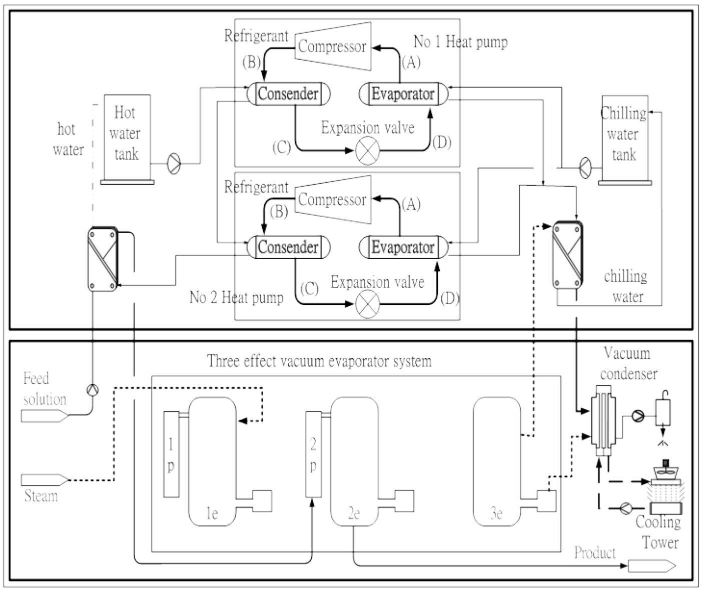

Figure 2 Heat pump and evaporator system (TEVEHP) schematic and flow diagram

A TEVE increases the concentrated solution as an endothermic activity and releases steam as an exothermic activity. These two activities correspond with the heat pump functions, which are capable of absorbing and discharging heat. A heat pump has both heat absorption (refrigerant vaporization) and heat discharge (refrigerant condensation) functions and can use refrigerant to balance the energy. The refrigerant absorbs heat from a relatively low temperature source, then compresses it, transports it to a relatively high temperature source, and releases the heat. Refrigerant is recovered and reused. The waste heat can be recovered for reuse and the goal of energy-saving and cost reduction can be reached.

The exothermic and endothermic energy was calculated by (1).

$$Q = m \times Cp \times \Delta T = m \times \Delta H \quad (1)$$

where Q is the heat-transfer rate, m is the mass flow rate, Cp is the specific heat, ΔT is the temperature difference, and ΔH is the enthalpy difference.

The two heat pumps sets were the water-to-water type (WWHP-010DB, Forever-Friend, Taiwan) and the refrigerant was R134a. Table I lists the specifications of the two heat pump sets. In this study, the heat pump (Fig. 2) directly used refrigerant to absorb waste heat from the TEVE emission

steam, which replaced the fractional cooling water that absorbed the discharged steam heat in the vacuum condenser from the TEVE. The refrigerant was vaporized and changed into a gaseous state (D→A), and the steam was condensed and released from the TEVE. The gaseous refrigerant was then compressed (A→B). The compressed energy in the refrigerant was discharged to preheat the concentrated solution of the TEVE (B→C). Finally, the refrigerant passed through an expansion valve to release pressure (C→D) and the temperature was returned to its original state. The refrigerant was recycled and the process was repeated [20].

TABLE I THE SPECIFICATIONS OF THE HEAT PUMPS

1st Heat Pump					
Kinds	Flow Rate m^3/h	Temperature Input (°C)	Temperature Output (°C)	Energy[a] kWh	COP[b] kW/kW
Chilling water side	5.4	12	7	31.4	2.42
Hot water side	7.6	44	49	44.2	3.40
Total	-----				5.82
Electric power	13.0 kWh				
2nd Heat Pump					
Kinds	Flow Rate m^3/h	Temperature Input (°C)	Temperature Output (°C)	Energy[a] kWh	COP[b] kW/kW
Chilling water side	5.4	12	7	31.4	2.18
Hot water side	7.6	49	54	44.2	3.07
Total	-----				5.25
Electric power	14.4 kWh				

a. Output energy is calculated by (2).

b. The heat pump COP value is calculated by (1).

Because hot water was required to satisfy the temperature demand, the two sets of heat pump condensers were connected in series to increase the temperature of the output water (Fig. 2). The chilling water was used to absorb the exhaust heat from the TEVE, which did not have the temperature limitation. Exhaust heat was sufficient. These two sets of heat pump evaporators were connected in parallel to reduce pressure loss. A coefficient of performance (COP) value was used to evaluate the energy efficiency of a system. The COP values of the heat pump were obtained by (2). The different COP values in these two heat pump sets were mainly attributed to the different demand of hot water temperature that was needed to adjust compressor loading rather than different electric power loading.

$$COP = W / E = (E + Q_a) / E = 1 + Q_a / E \qquad (2)$$

where the per unit energy input (E) combined with the absorption energy (Qa) produces an amount of energy output (W) from the system. With an efficient heat pump design, exothermic COP values can be greater than 3.0; therefore, 1 kW of electric power input into the heat pump will generate at least 3 kW of hot water.

D. Calculation Algorithm Design and Simulation

When the TEVE operation condition reached steady state, the individual effect operation data were obtained using energy and mass balance conditions following the calculative procedures listed in Fig. 3. Table II shows the required measuring data, hypothesis data, and the resulting concentration and flow rate of the gelatin solution. The required amount of steam and operation data in each individual effect used the energy and mass balance (3) to (7) listed in Table III. The measuring data shown in Table II were directly obtained from the production line and the steam enthalpy was obtained from the measured steam temperature table [21].

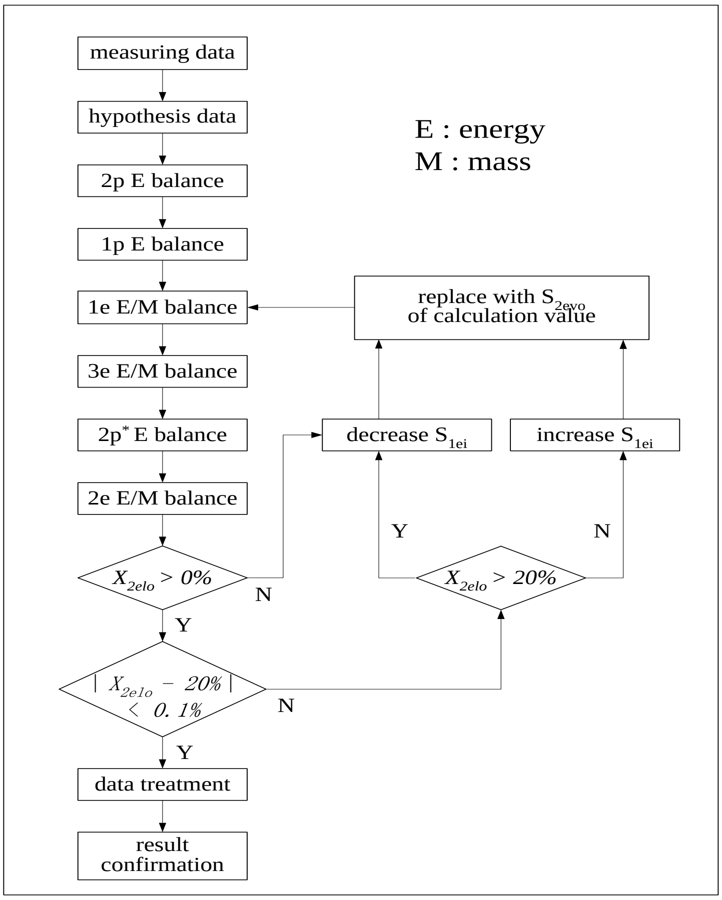

Figure 3 Flow chart of the developed algorithm

The output gelatin concentration at the second effect was evaluated to determine the next step using two criteria, which were whether the concentration was a negative value and whether the calculated concentration was a convergence to the hypothesis concentration 20 ± 0.1%, respectively. When the outcome did not satisfy the criteria, the quantity of input steam at the first effect was adjusted and recalculated following the new condition and calculative procedures shown in Fig. 3. The final verification of the results was confirmed by the total energy and mass balance equations, (8) to (10) shown in Table III.

TABLE II CONTRAST TABLE: PARAMETER MEASUREMENTS, HYPOTHESIS DATA, AND UTILIZATION EQUATION OF EACH UNIT IN EACH CALCULATION PROCEDURE.

Device	Measuring Data	Hypothesis Data	Energy and Mass Balance	Equation No.
2p	L_{2pi} / X_{2pi} / T_{2pi}/ T_{2po} / T_{2psi} / T_{2pso}		Get steam quantity S_{2pi}	(3)
1p	T_{1po} / T_{1psi} / T_{1pso}		Get steam quantity S_{1pi}	(3)
1e	T_{1esi}/T_{1eso}/ T_{1psi}/T_{1elo}/T_{1evo}	Set input steam quantity S_{1ei} (arbitrary value)	Get L_{1eo}/X_{1elo}/S_{1evo}	(4) to (7)
3e	T_{3elo}/T_{3evo}/T_{3esi}/ T_{3eso}		Get L_{3eo}/X_{3elo}/S_{3evo}	(4) to (7)
2p*	T^{*}_{2po}/T^{*}_{2psi}/T^{*}_{2pso}		Get steam quantity S^{*}_{2pi}	(3)
2e	T_{2elo}/T_{2evo}/T_{2esi}/ T_{2eso}/S_{1eo}/T_{1eso}	Set output vapor quantity S_{2evo} (arbitrary value)	Get L_{2eo}/X_{2elo}/S_{2evo}	(4) to (7)

NOTE: Item defintions are listed in nomenclature Table.

TABLE III THE DESCRIPTION OF ENERGY AND MASS BALANCE

Equation	Equation No.	Description[a]
Pre-heater		
$L_{npi} \times Cp \times (T_{nplo} - T_{npli}) = S_{npi} \times (H_{npsi} - H_{npso})$	(3)	EB
Evaporator		
$L_{nei} = L_{neo} + S_{neo}$	(4)	MB
$Lnei \times Xnei = Lneo \times Xneo$	(5)	MB
$L_{nei} \times H_{nei} + S_{nei} \times H_{nesi} = S_{nevo} \times H_{nevo} + L_{neo} \times H_{nelo} + S_{npi} \times H_{npsi} + (S_{nei} - S_{npi}) \times H_{neso}$	(6)	EB
$S_{nevo} = S_{(n+1)ei}$	(7)	MB
Total Energy and Mass Balance		
$L_{2pi} = L_{1pi} = L_{1ei} = S_{1evo} + S_{2evo} + S_{3evo} + L_{2eo}$	(8)	MB
$L_{1ei} \times X_{1ei} = L_{1eo} \times X_{1eo} = L_{3eo} \times X_{3eo} = L_{2eo} \times X_{2eo}$	(9)	MB
$L_{2pi} \times H_{2pli} + S_{1ei} \times H_{1esi} = S_{1pi} \times H_{1pso} + (S_{1ei} - S_{1pi}) \times H_{1eso} + S_{2pi} \times H_{2pso} + (S_{2ei} - S_{2pi}) \times H_{2eso} + S_{2eso} \times H_{3eso} + L_{2eo} \times H_{2elo} + S_{3evo} \times H_{3evo}$	(10)	EB

a .EB is the energy balance and MB is the mass balance.

NOTE: Item defintions are listed in nomenclature Table.

TABLE IV THE SIMULATION OPERATION DATA

Side	Item	Unit	2nd Effect Pre-Heater	1st Effect Pre-Heater	1st Effect Evaporator	3rd Effect Evaporator	2nd* Effect Pre-Heater	2nd Effect Evaporator
Gelatin	Inlet	Flow rate (kg/h)	7,500	7,500	7,500	5,291	3,018	3,016
		Temperature (°C)	44[a]	62	64	78	41	62
		Concentration (%)	3	3	3	4.3	7.5	7.5
		Energy (kW)	384	541	558	480	144	217
	Solution Outlet	Flow rate (kg/h)	7,500	7,500	5,291	3,018	3,018	1,125
		Temperature (°C)	62	64	78	41	62	46
		Concentration (%)	3	3	4.3	7.5	7.5	20.0
		Energy (kW)	541	558	480	144	218	60
	Vapor Outlet	Flow rate (kg/h)	---	---	2,209 [b]	2,273	---	1,890
		Temperature (°C)	---	---	88	40	---	68
		Enthalpy (kJ/kg)	---	---	2,657	2,574	---	2,624
		Energy (kW)	---	---	1631	1,626	---	1,378
		Pressure (kPa)	---	---	68	7	---	30
Steam	Inlet	Flow rate (kg/h)	239[b]	27[c]	2,378[c]	1,890	112[b]	1,858[b]
		Temperature (°C)	88	135	135	68	88	88
		Enthalpy (kJ/kg)	2,657	2,727	2,727	2,624	2,657	2,657
		Energy (kW)	176	20	1,802	1,378	83	1,372
		Pressure (kPa)	68	325	325	30	68	68
	Outlet	Flow rate (kg/h)	239	27	2,378	1,890	112	1,858
		Temperature (°C)	70	90	90	40	70	70
		Energy (kW)	19	3	249	88	9	151

a. The temperature of the inlet gelatin solution is 44 °C. The TEVE system is operated under heat pump useless

b. The vapor from the 1st effect evaporator was 2,209 kg/h, which was the input to the 2nd effect evaporator and pre-heater.

c. The flow rate of the steam was 2,405 kg/h, which was the input to the 1st effect evaporator and pre-heater.

III SIMULATION RESULTS

A. Conventional Gelatin TEVE Process

In this study, the heat source was 135 °C, 320 kPa-saturated steam. The TEVE was used to replace the general evaporator at the same operating condition in a gelatin plant. The 7,500 kg/h gelatin solution was heated from 44 to 100 °C and concentrated from 3% to 20% by the conventional evaporator, indicating 6,375 (=7,500×(1-0.03/0.2)) kg/h of water would be evaporated. The working time of the equipment was 330 days yearly and 24 hours daily. The data shown in Table IV simulated the whole operating data of the non-heat pump individual evaporator under energy and mass balance, following the procedures shown in Fig. 3. Equation (1) was used. The amounts of steam and energy requirements were 2,405 (=27+2,378) kg/h and 1,822 (=20+1,802) kWh, respectively, to supply the first effect and pre-heater that consumed 170.4 (=1,822/10.69) L/h fuel oil (fuel oil heat value is 10.69 kW/L). The operating fees of the TEVE are shown in Table V. Annual operating cost was US$ 703,203.

TABLE V THE OPERATING COST OF THE THREE-EFFECT EVAPORATOR (TEVE).

Energy Type	Quantity	Unit Price	Cost[a]
Fuel Oil	170.4 L/h	485 US$/kL	82.6 US$/h
Vacuum Pump	5.595 kWh	0.08 US$/kWh	0.4476 US$/h
Delivery Pump	27.4 kWh	0.08 US$/kWh	2.16 US$/h
Cooling Tower	44.8 kWh	0.08 US$/kWh	3.5808 US$/h
Total	---	---	88.7884 US$/h

a .The total cost for the whole year (330 days by 24 hours/day) is US$ 703,203.

B. Advanced Gelatin TEVE Process (TEVEHP)

The TEVE feed temperature was 44 °C without the heat pump preheating. Each effect of operating data is shown in Table IV. After adding the heat pump, with the specifications of the two heat pump sets shown in Table I, 62.8 (=31.4+31.4) kW of heat energy was absorbed from TEVE emission and the total power demand of the compressor was 27.4 (=13.0+14.4) kWh. Therefore, the heat pump supplied 88.4 (44.2+44.2) kW of energy to preheat 3% 7,500 kg/h gelatin solution, which resulted in the temperature increase to 54 ℃. Using the same calculating process in Fig. 3, when the temperature of the feed solution was 54 °C and other operating conditions were identical to those in Section II.D, the energy and mass balance of each effect in the TEVEHP can be calculated. The fuel oil and cooling water decreased 8.2 (=88.4/10.69) L/h and 10.8 (=62.8×0.86/5) m^3/h (the temperature difference of cooling water was 5 ℃), respectively.

The endothermic function of the heat pump was applied to the vacuum condenser and reduced the total cooling water amount from 260 m3/h to 250 m3/h. The total year (330 days) waste heat discharge to the atmosphere was decreased by 460,465 kW; the calculation is under a temperature difference of 5 ℃ between the input and the output of the cooling tower. The waste heat emission was already decreased a great amount to reduce the atmospheric heating load and environmental pollution problem. Nevertheless, cooling water only decreased at 10.8 m3/h; it was not an obvious cost benefit. Therefore, the endothermic efficiency of the heat pump was neglected in the calculations.

As shown in Table V, the power consumption of the heat pump increased 27.4 kWh, but the combustion amount of fuel oil decreased 8.2 L/h. The price of electrical power and fuel oil are US$ 0.08/kWh and US$ 485/kL, respectively. With the heat pump (TEVEHP), the yearly (330 days) electric power cost increased US$ 17,361 but the fuel oil cost demand decreased US$ 31,613. The total cost decreased by US$ 14,252 yearly (not contain maintenance cost).

C. Simulated a Multiple Equation

Table IV shows the total simulation operation parameters for the TEVE. When the TEVE was assisted by the heat pumps, the input gelatin temperature (T1pli) gradually increased from 44 to 54 °C. With the same input gelatin loading (L1ei) and output gelatin concentration (X2elo), the operation data of different steam requirements can be obtained by the computation method listed in Fig. 3. In the same way, when both the steam loading (S1ei) and output gelatin concentration (X2elo) were kept constant, the different input gelatin loadings (L1ei) were obtained following the same calculation method. When both input gelatin loading (L1ei) and steam loading (S1ei) were kept constant the different output gelatin concentrations (X2elo) were obtained using the same calculation method.

Using the aforementioned method, the simulated results of the different parameters (input gelatin loading, input gelatin temperature, output gelatin concentration, and steam loading) were obtained at different conditions. These conditions included input gelatin loading (L1ei) ranging from 6,500 to 8,500 kg/h, input gelatin temperature (T1pli) ranging from 44 to 54 °C, steam loading (S1ei) ranging from 2,200 to 2,500 kg/h, and output gelatin concentration (X2elo) ranging from 16 to 28%. The simulated results were regressed by a multiple equation, which is shown in (3). The regression coefficient was 0.999.

$$L_{1ei} = 2.580348 \times S_{1ei} - 18.6374 \times T_{1pli} - 137.70438 \times X_{2elo} + 1.13095 \times 10^{-5} \times S^2_{1ei} + 0.078444 \times T^2_{1pli} + 2.60057 \times X^2_{2elo} + 0.01957 \times S_{1ei} \times T_{1pli} + 0.477602 \times T_{1pli} \times X_{2elo} - 0.003987 \times S_{1ei} \times X_{2elo} - 0.00035 \times S_{1ei} \times T_{1pli} \times X_{2elo} + 1996.6191 \quad (3)$$

where the item definitions are listed in nomenclature table.

IV. DISCUSSION

A. A Heat Pump is a Full-Scale Suitable Device Used to Recover Waste Heat

The waste heat emission from a plant is recovered either directly or indirectly. Generally, waste heat emission is accompanied with waste gas or water; nevertheless, waste gas or water is already contaminated and cannot be directly recovered. In the way of indirect recovery, heat exchanger is

often used to recover waste heat from waste gas and water. The heat exchanger uses water as a medium, but the low temperature of the waste gas or water resulted in the low efficiency of heat recovery. Hence, the heat exchanger needed a large module to enhance efficiency, which resulted in a high investment cost. That is the possible reason the waste heat in the factory was not recovered and was directly discharged to the ambient atmosphere. The waste heat discharge to the atmosphere is not only energy consumptive but it causes high production cost and is also an environmental pollution.

A heat pump is an excellent heat recovery piece of equipment. In this study, the refrigerant of the heat pump was R134a with a molecular formula is CH2FCF3. The molecular weight is 102.03, and the vaporization temperature is very low at -26.1 ℃ [22], and is used as the medium of heat exchange. Although, the waste heat temperature was also low, it was obviously higher than the vaporization temperature of R134a. Hence, the R134a could be used at a small module heat exchanger to absorb a great amount of heat energy and to accomplish waste heat recovery. That meant all types of waste heat in the factory can be recovered by R134a (refrigerant) with a small module heat exchanger and reused by heat pump.

In this study, the temperature of the waste heat from the TEVE emission steam was 50 °C. Nevertheless, the heat pump still absorbed 62.8 kW energy, after compression, 88.4 kW of heat energy from heat pump was discharged to preheat the TEVE feed solution. The annual fuel oil use can further decrease 65.2 kL. The fraction of waste heat reduced from the TEVE emission only decreased 10.8 m3/h of cooling water utilization amount in the vacuum condenser. If the endothermic function of the heat pump combines with the factory chilling system, it can make 10.8 m3/h low temperature (7 - 12 °C) chilling water and hence reduce a huge cost of chilling water production.

B. Assessment the Investment Efficiency of the Heat Pump

The heat pump investment was assessed by the net present value (NPV) method shown in (4).

$$NPV = \sum_{t=1}^{t=N} CF_t \big/ \left(1 + r^2\right) - C_0 \tag{4}$$

where NPV is the summation of the net cash flow (CFt) in the period (t=1 to N) divided by 1 plus the squared discount rate (r) minus the initial costs of investment (C0).

NPV is a primary investment decision criterion. This method involves calculating the present value of all yearly capital costs and savings throughout the life of a project. The NPV sums all these present values (costs being represented as negative amounts and net savings as positive) of this project. If the NPV is positive then the project would be accepted, otherwise, it would be rejected [23].

In this case study, the heat pump investment cost was US$ 11,000, which included two new heat pump sets worth US$ 9,000, and piping connections and insulation worth US$ 2,000. The manpower, the expenses of the equipment operation, and the maintenance were not increased; therefore, the yearly system maintenance expense was set at 10% of the investment cost, US$ 1,100. After installation of the heat pumps, and deducting the US$ 1,100 maintenance expenses, the total annual operation cost further saved US$ 13,152. The NPV of US$ 38,856 was based on the 10% discount rate of investment cost and 5 years operation of the equipment. The investment expense can be completely recovered in 10 months. Because the NPV is a positive value and the break-even time is very short, this TEVEHP procedure would be a good investment.

C. Evaluation of Maximum Benefit of the TEVEHP

Equation (11) can provide the optimal operation and make different production decisions between the operation cost and product yield for the decision-maker. For example, the main purpose of this simulation was to reduce energy consumption. The TEVE was assisted by the heat pump to preheat the input solution temperature from 44 to 54 °C (T1pli). At simulated conditions mentioned in Section II.D, the annual operation cost decreased US$ 13,152. When increasing the amount of gelatin is the priority task, the expected maximum production capacity of 295 kg/h can be calculated by (11), which is an increase of 3.9% in the case study.

With the same method, if the output gelatin concentration (X2elo) is expected to be the priority task, the expected output gelatin concentration of 26% can be calculated by (11). The simulation result of this operation system can also be verified and adjusted by (11). That is useful for cost management and operational simplification.

In addition, the simulation and calculation result of the operational system is in a normal condition and the energy utilization and raw materials are in reasonable ranges, which can all be checked and adjusted by (11).

VI. CONCLUSION

Vaporized concentration is not only an energy consumptive process but also generates a high operating cost in the food industry. The conventional TEVE is energy-conservative and can save large amounts of heat energy. The purpose of this study was to further enhance the energy utilization efficiency and reduce production cost without change operating parameters under current TEVE use. In this study, the process used a TEVE with a heat pump (TEVEHP) to absorb the waste heat from the evaporator, and transferred the energy to raise the temperature of the input gelatin solution in the evaporator. Therefore, the TEVEHP can reduce the cooling water and boiler steam requirements at the same time. The total decrease in fuel oil and cooling water was 8.2 L/h and 10.8 m3/h, respectively. The relationship between the input gelatin loading, input gelatin temperature, output gelatin concentration, and steam loading of the TEVE was simulated at steady-state operation condition. The simulated results can be used to make different production decisions between the operating cost and product yield for the decision-maker.

Factories usually require and discharge a large amount of heat energy at the same time. If the endothermic and

exothermic of the heat energy can be balanced, not only can energy be saved but also the cost saving can be reached.

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NOMENCLATURE

W	output energy (kilo Watt, kW)
E	input energy (kW)
Q_a	absorption energy (kW)
COP	coefficient of performance (kW/kW)
Q	heat-transfer rate (kJ/h)
m	mass flow rate (kg/h)
Cp	specific heat (kJ/kg K)
ΔT	the difference in temperature (K)
ΔH	the difference in enthalpy (kJ/kg)
H	enthalpy (kJ/kg)
T	temperature (°C)
L	flow rate of gelatin solution (kg/h)
S	flow rate of steam (kg/h)
X	concentration of gelatin solution (%)
t	the number of periods
CF_t	the net cash flow in a time period
C_o	initial costs of investment
r	the discount rate
N	the expected number of the whole period

SUBSCRIPTS

n	no of 1, 2, 3
i	input
o	output
e	evaporator
p	pre-heater
s	steam
l	liquid
v	vapor
c/w	cooling water

REFERENCES

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